Hydric soil development in the Olentangy River Experimental Wetlands after five years of inundation

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Introduction

The most important parameters which define a wetland, are its hydrology, the vegetation that it supports, and the presence of hydric soils. Hydric soils are defined as, 'soils formed under conditions of saturation, flooding, or ponding, that lasted long enough during the growing season to develop anaerobic conditions in the upper part' (Soil Conservation Service, 1994). Such soils are consequently highly reduced, and support processes normally seen under such conditions. Hydric soils are used as indicators in the delineation of wetlands. Wetland boundaries are located where hydric soils end and upland soils begin.

The level of reduction in a soil can be measured in two ways; (a) by determining the redox potential of the soil, and (b) by determining the chemical composition of the soil solution. The redox potential can be measured using a Pt electrode, a standard reference electrode, and a meter that measures voltage. Sometimes dyes which demonstrate different colors under oxidized and reduced conditions are use to detect the presence of reduced species (Childs, 1981).

Hydric soils have been extensively studied, but sometimes are difficult to identify (Vepraskas, 1997). The purpose of this study was to determine the physical and chemical properties of soils in the two experimental basins in the Olentangy River Wetland Research Park (ORWRP) five years (six growing seasons) after flooding began and to compare the data with results from previous years. The properties of interest were color, moisture content, bulk density, OM content, C content, and redox potential.

Materials and Methods

Study site

The Olentangy River Wetland Research Park (ORWRP) is a 10-ha created wetland complex located on the northern end of the Ohio State University campus. The ORWRPlies within the floodplain of the Olentangy River, and is underlain with glacial outwash deposit, which varies from 33-83 m in depth. Two freshwater marsh basins (Figure 1), each of which has an area of 1 ha, were built in 1993 and first flooded in March 1994. Since then, water has been continuously pumped at similar rates in both basins to maintain uniform hydrology. Water from the Olentangy River enters at the northern end and leaves from the south. These basins also have a hydrologic gradient within them, with deeper sections continuously flooded and edges less frequently flooded.

Sampling and soil color

Samples were drawn from different parts of both basins (Figure 1). Each basin has three deeper sections, and one sample was drawn from each of these areas. In addition one sample each was drawn from the shallow, transitional zone, and upland zones in each basin (Figure 1). A hand-held stainless steel probe with an inner diameter of 2 cm was used for taking soil samples. The probe was inserted vertically into the soil far enough to fill it, but not so far as to compress the sample. The probe was removed very carefully so as not to disturb its natural structure and packing (Petersen, 1986). Approximately 20 cm long sample cores were drawn at each location. Only intact cores were accepted, allowing accurate calculation of the volume. Each core was carefully sliced with a straight-edged knife, and examined for possible demarcation lines. Each separate zone of the core was compared with the Munsell color chart in the field to arrive at a good match for the color, value, and chroma. The thickness of the top muck layer, and lengths of the different zones in the cores were noted, and each zone was collected separately in a pre-weighed aluminum moisture tin with a lid. The samples were immediately placed in a cooler until further analysis.

Moisture content and bulk density

Moisture tins with soil samples were weighed before placing in an oven at 105^{o}C for a 24 hr period. At the end of this period, they were weighed and the procedure was repeated until a constant mass. The moisture content (*w*) of the sample was determined by calculating the loss of mass upon heating as a percent of the mass of solids after drying (Gardner, 1986). The area of cross-section of the sample probe, and length of the sample was used for calculating the volume of each sample. The bulk density (r_b) was calculated by dividing the mass of solids (dry mass) by the total sample volume (initial) (Blake, 1986).

Total organic matter content

Total OM content was estimated by loss on ignition at 550^{o} C (Nelson, 1982). The oven-dried samples were crushed, ground, and sieved through a 0.5 mm sieve. A sub-sample of known mass of each sample (approximately 2 g) was placed in a pre-weighed glass vial. The vials were placed in a muffle furnace at 550° C for 24 hrs. The vials were weighed after removing from the furnace. The loss in mass as a percentage of the initial mass gave the total OM content of the sample.

Total carbon

Total C was determined by the dry combustion method at 950° C (Nelson, 1982). MnO_2 0.25 g was evenly distributed along the inside bottom of a ceramic boat. Approximately 2 g of ground and sieved soil sample was weighed and evenly distributed over the MnO_2 along the inside bottom of the ceramic boat (Figure 2). An ascarite bulb was weighed and recorded as initial weight. The boat was pushed into the Vycor glass tube of the furnace, and the O_2 supply was started. The evolving CO_2 was sorbed into the ascarite after running it through a dessicating medium. The ascarite bulb was disconnected and weighed for final weight. The difference between the initial and final weighed the bulb gave the amount of CO_2 evolved, from which the corresponding total C content was calculated. Different quantities of $CaCO_3$ standards were run simultaneously for calibration.

Inorganic carbon

Approximately 1g of sieved soil was weighed and transferred into a 250 ml reaction flask with a dry stir bar (Dreimanis, 1962). The initial barometric pressure was recorded. 20 ml of concentrated HCl was added from the buret to the flask. The volume of CO_2 generated was measured at time 30 sec and 40 min. The corresponding temperatures and pressures were also recorded. The readings for time 30 sec corresponded to the quantity of $CaCO_3$ in the sample, whereas those at 40 min corresponded to the total quantity of $CaCO_3$ and $MgCO_3$. The volumes of CO_2 were converted into amounts of the respective carbonates by using the appropriate mathematical relations.

Redox potential

Water initially present in the monitoring wells situated in the wetland, transitional, and upland zones in the planted basin was bailed out, and the wells were allowed to recharge with water recently associated with the root zone. A H_2OG water quality probe was inserted to measure the redox potential (mV), dissolved oxygen (mg/l), temperature (° C), pH, and conductivity (mS/cm). Unfortunately the wells in the unplanted basin were dry when the measurements were carried out, and hence could not be studied.

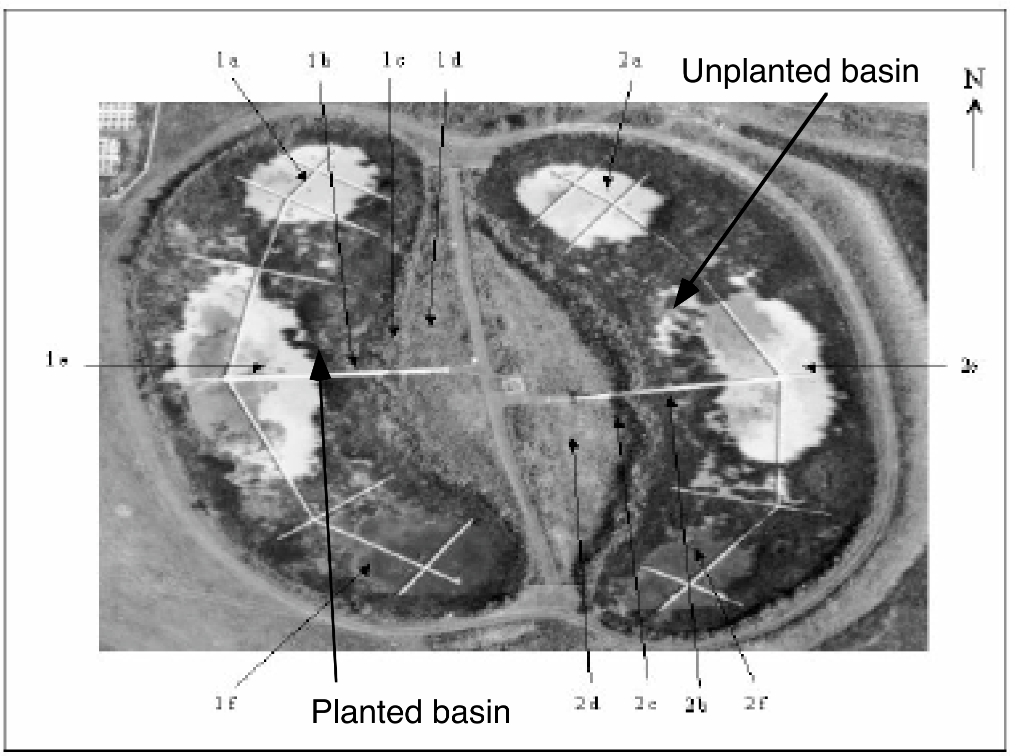

Figure 1. Map of the experimental basins at the Olentangy River Wetland Research Park site with sampling points. 1 = Planted basin, 2 = Unplanted basin.

Results and discussion

Soil color

All samples from the deeper parts of the basins, except those on the western side of wetland 2 (2e) were observed to be hydric with a chroma of 2 or less (Table 1). The commonly observed hue was 10YR. The soils from the western Wetland 2 were found to be yellowish-brown, as compared to the darker brown shades seen at 5 sites (1a, 1f, 2a, 2e, and 2f). The soils from the shallower parts, transitional zones, and upland zones had chromas higher than 2. In general, the chroma values increased with soil depth in the experimental basins (i.e., the deeper soils showed presence of oxidized Fe).

Soil samples from the shallower parts of the basin, the transitional zones, and the upland zones did not have a visible separate muck layer. The muck layer, whose thickness varied from 2-8 cm, had a high algae fiber content which gave it a yellow-green color. The thickness of the muck layer was greater in the unplanted basin (wetland 2) as compared to the planted basin (wetland 1), indicating a higher productivity for the former (Figure 3).

A history of soil color in the basins is given in Table 2. Before the basins were flooded (1993), the most prevalent hue was 10YR, and the color varied between 3/3 and 3/4 (Nairn et al, 1994). In 1995, values and chromas of three or less were common (median = 3/2) (Nairn and Mitsch, 1996). The mean value in the surface samples was 3/2 and that in the sub-surface samples collected was 4/2. Chromas started to consistently be of 2 or below in 1996, 2 years after flooding began.

Table 1. Color of soil samples from the experimental basins at the Olentangy River Wetland Research Park (1999).

Sample*	Hue	Value	Chroma
1a top	10YR	3	2
1a bottom	10YR	4	2
1e top	10YR	3	1
1e bottom	10YR	3	2
1f top	10YR	3	1
1f bottom	10YR	4	2
2a	10YR	3	2
2e top	10YR	5	3
2e middle	10YR	4	3
2e bottom	10YR	3	1
2f	10YR	3	1
1b	10YR	3	2
2b	10YR	3	2
1c	10YR	3	3
2c	10YR	3	3
1d	10YR	3	3
2d	10YR	3	4

1* = Planted basin
2* = Unplanted basin

Other studies on constructed wetlands have shown that chromas of soils from constructed wetlands are higher when compared with those from natural wetlands, even over longer periods, primarily due to the lower OM content (Bishel-Machung, 1996; Confer, 1992). Also, soils from constructed wetlands show far less mottling, and reduced gleying phenomenon as compared to natural wetlands (Bishel-Machung, 1996; Confer, 1992).

Moisture content and bulk density

Surface soils from the deeper parts of the basin were mucky in texture. The height of the top muck layer was measured and it was separated from the rest of the sample, before the w and r_b measurements were carried out. w values varied between 23% and 67%. In general, surface soils had higher w values as compared to deeper soils. The mean bulk density (r_b) for the deeper parts of the experimental basins is 1.33 ± 0.27 g/cm^3, while for the shallower parts it is 1.24 ± 0.02g/cm^3, and for the transitional and upland zones it is 1.26 ± 0.18 g/cm^3. Overall, the r_b varied between 0.8-1.55 g/cm^3, and increased with depth (Figure 4). Surface soils, which were richer in OM, had lower r_b as compared to the sub-surface mineral soils. This observation is supported by the data for total OM determined by ignition. The deeper parts of the planted basin had an average r_b of 1.2 g/cm^3, whereas those of the naturally colonizing unplanted basin had an average of 1.48 g/cm^3. In the transitional and upland zones, soils from the unplanted basin had lower r_b as compared to that from the planted. This points to the fact that the planted basin has a higher net productivity in the deeper parts, whereas the unplanted basin has a higher net productivity in the transitional and upland zones. The average r_b (1.3 ± 0.23 g/cm^3) was lower than measurements in previous years except for the years 1993 and 1995 (Figure 5).

Table 2. Change in soil color of the constructed wetland basins in the Olentangy River Wetland Research Park, 1992-1999.

Year	Color
1993	3/3 to 3/4
1994	3/3 to 4/3
1995	3/2 to 4/3
1996	3/2
1997	2/2 to 3/3
1998	2/0 to 3/2
1999	3/2

Note: Values for 1993 to 1997 are from previous studies (Nairn et al., 1994; Wang et al., 1995; Nairn and Mitsch, 1996; Ahn and Mitsch, 1997; Gilbert et al., 1998)

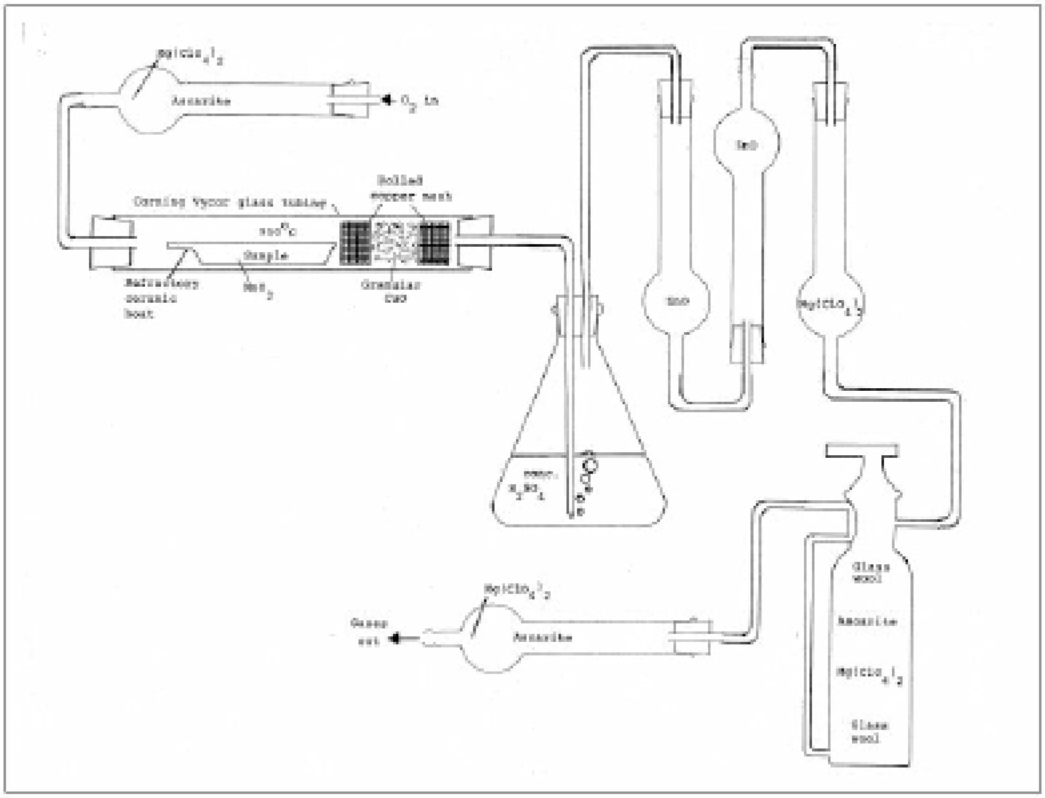

Figure 2. Experimental setup used for measuring total carbon.

Total organic matter

Total OM content computed from loss on ignition, confirms the trend seen in the r_b measurements. In general, the surface soils had higher total OM as compared to the subsurface soils (Figure 6). This can be expected from the continuous addition of fresh OM to the surfacial soils by both vegetation and algae. This method of determination of total OM however suffers from a limitation due to loss of water of hydration from aluminosilicates at high temperature, and a consequent overestimation of the organic matter content. The total OM content varied between 5.1-6.7 %. The average value for the deeper sections of the planted wetland was 5.6 $\pm$ 0.66 %, whereas that for the unplanted was 5.5 $\pm$ 0.35 %. It is interesting that upland soils and those from the transitional zones had higher OM content (average 6.4 $\pm$ 0.32 %) compared to soils from the deeper parts of the basins. This observation is supported by the organic C analyses of these samples as described below.

Total carbon and inorganic carbon

The total C content was in line with the total OM content, and varied between 1.09 to 3.44%. Although the highest C content was found in sample 1a, the shallow, transitional, and upland zones had higher C content than the other samples from the deeper sections. Sample 1a also had higher carbonate content, which explains its unusually high C content. Total C content was higher for surface soils as compared to sub-surface soils (Figure 7). With the exception of sample 1a, which was found to have about 1% carbonate, all other samples had little or no carbonates. Thus most of the carbon in these samples is organic in nature. The average organic C (OC) content for the deeper sections of the planted basin was 1.48 $\pm$ 0.48%, whereas for the unplanted basin it was 1.43 $\pm$ 0.34%. The shallow portions of these basins had a OC content of 1.98 $\pm$ 0.14%, the transitional zones, 1.95 $\pm$ 0.39%, and the upland zones 2.16 $\pm$ 0.07%. Upland soil samples had a higher carbon content as compared to those from the basins.

Soil water in gradient

For all three monitoring wells, redox potentials are in the aerobic range (Table 3). (pe + pH) calculations indicate that the values for all three locations are >12 (mean 17.4 $\pm$ 0.2) pointing to oxidized conditions. Mean pH was 7.4 $\pm$ 0.13. Mean temperature of soil solution was 12.7 $\pm$ 2.6^o C, and the dissolved oxygen varied from 2.0 to 3.7 mg/l.

Table 3. Data from the experimental wells in the experimental basins at the Olentangy River Wetland Research Park.

Location	Temp	DO[a]	Conductivity[b]	pH	Redox Pot[c]
Units		(°C)	(mg/l)	(mS/cm)	(mV)
1b (wetland)	10.39	3.3	557	7.6	568
1c (transitional)	12.2	3.7	880	7.3	602
1d (upland)	15.6	2.0	491	7.3	599

DO[a] = Dissolved oxygen
Conductivity[b] = Ionic conductivity
Redox Pot[c] = Redox potential

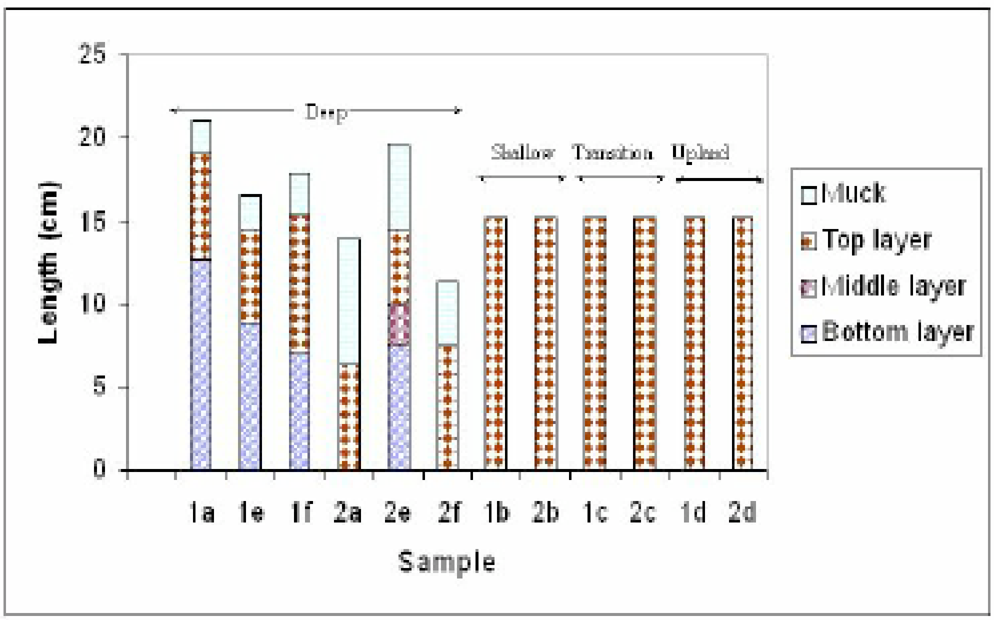

Figure 3. Profile of the samples drawn from the planted and unplanted basins in the Olentangy River Wetland Research Park. 1 = Planted basin, 2 = Unplanted basin.

Conclusion

Soil properties such as soil color, bulk density, organic matter content, and organic C content are indicative of the biogeochemical processes occurring in a wetland. Extreme care has to be taken in the interpretation of soil color. Bulk density measurements are sensitive to volume measurements, and hence the techniques adopted for the same, have to be of a high quality. Determination of total carbon, and carbonates is more reliable as compared to determination of total organic matter upon ignition. The soils from the deeper parts of the experimental basins were found to be hydric, and those from the shallow parts, the transition zones, and the upland zones were not found to be hydric.

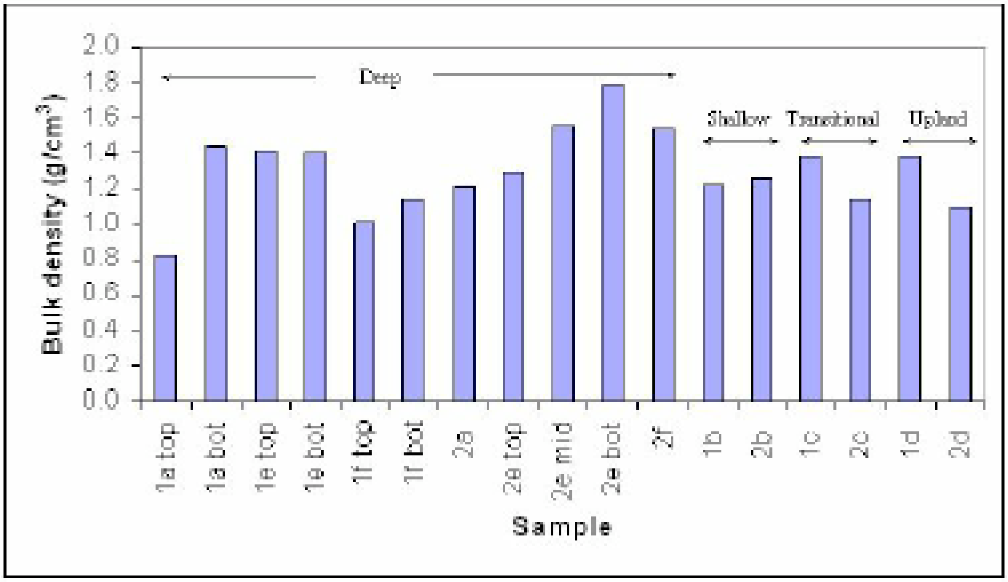

Figure 4. Bulk density (p_b) of soil samples drawn from the planted and unplanted basins in the Olentangy River Wetland Research Park. 1 = Planted basin, 2 = Unplanted basin.

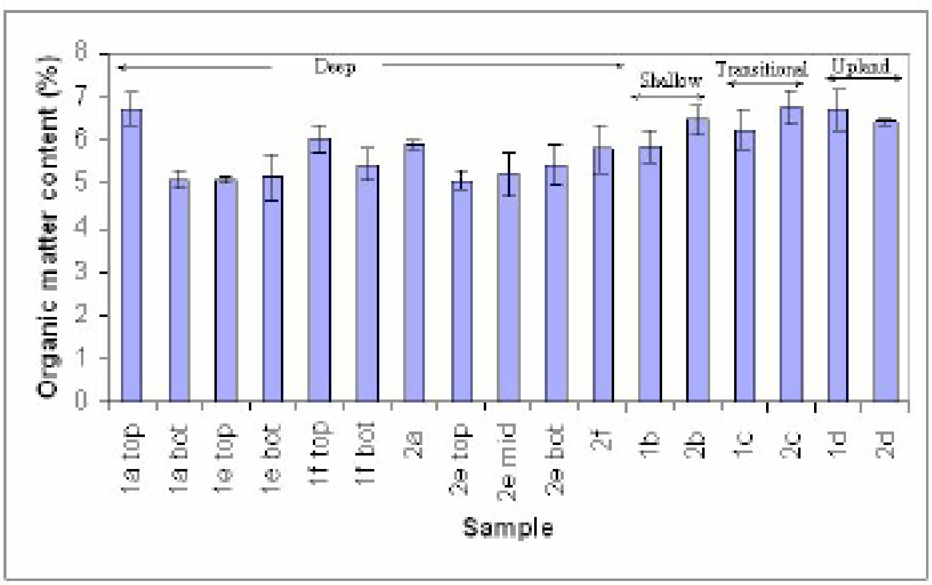

Figure 5. Variation in the average bulk density (r_b) in soil samples from the experimental basins at the Olentangy River Wetland Research Park between 1993 and 1999.

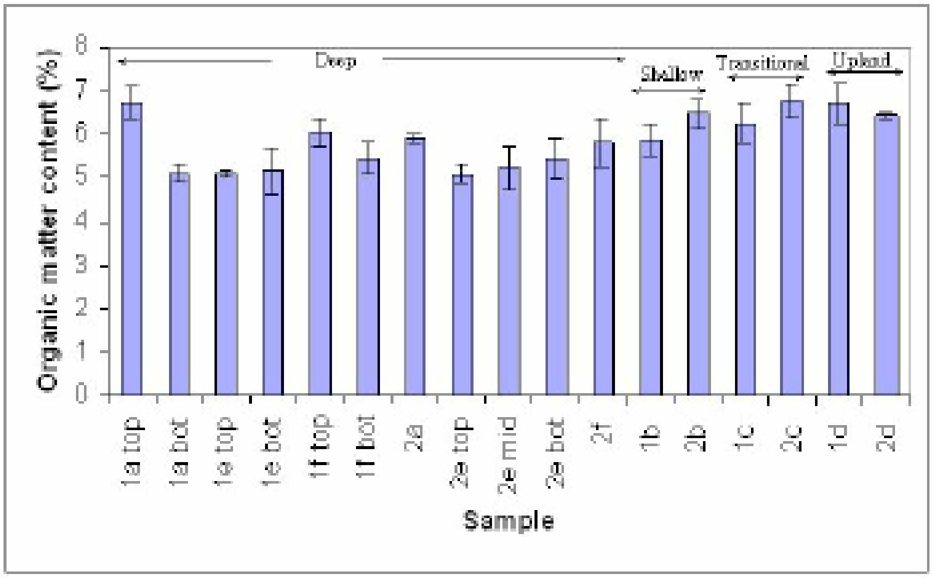

Figure 6. Total organic matter (OM) content of soil samples drawn from the planted and unplanted basins in the Olentangy River Wetland Research Park. 1 = Planted basin, 2 = Unplanted basin.

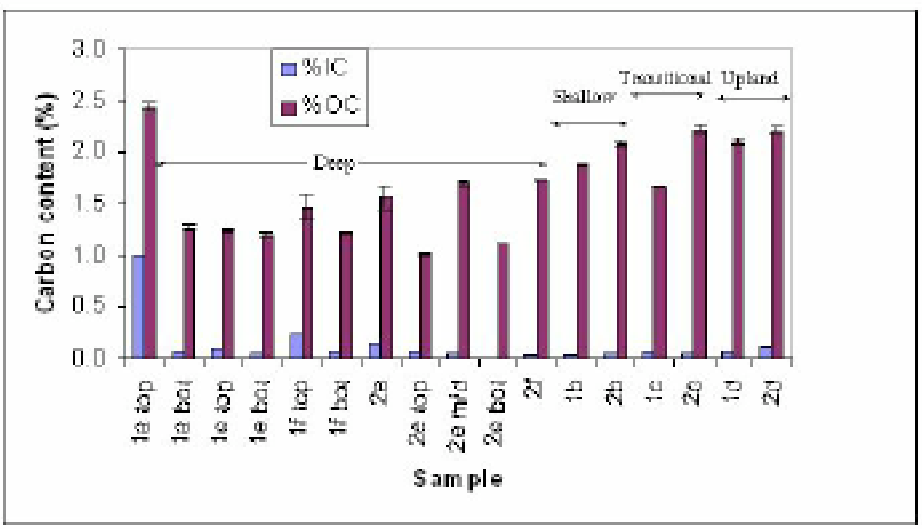

Figure 7. Organic and inorganic carbon content of soil samples drawn from the planted and unplanted basins in the ORWRP, %OC = % Organic carbon, %IC = % Inorganic carbon. 1 = Planted basin, 2 = Unplanted basin.

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